

FINAL
IN-89-CRO.CIT.
7886

p. 23

Final Technical Report for NASA Grant NAG 5-1134.
Cooperative Research in Space Sciences

This grant covered the period from July 1989 through September 30, 1995. The research covered a number of topics in the general area of space science. Specific research topics included

1. Solar astronomy - largely in support of the Ulysses project
2. Space Science - largely in support of instrumentation for several NASA satellite projects
3. Cometary astronomy
4. Planetary Astronomy - largely supporting the NASA Infrared Heterodyne instrument.

Details of the research projects are attached.

(NASA-CR-200129) COOPERATIVE
RESEARCH IN SPACE SCIENCES Final
Report, Jul. 1989 - 30 Sep. 1995
(Maryland Univ.) 23 p

N96-18520

Unclass

G3/89 0099865

III SUMMARY OF PROGRESS IN PAST 12 MONTHS

1. GEOPHYSICAL STUDIES

Several projects have been undertaken involving the development and calibration of advanced instrumentation for geophysical studies in the areas of the Earth's magnetic field, terrestrial lightning and plasma research. Most of the work has been done by Dr. Dennis Chornay in conjunction with the scientific staff in the Laboratory for Extraterrestrial Physics at the Goddard Space Flight Center.

The first project involved calibrating and verifying the correct operation of sensitive fluxgate magnetometers. This work was done using previously developed Ground Support Equipment (GSE) which operates in conjunction with a PC. The test of the magnetometers covered conditions in the laboratory, during environmental testing, and during spacecraft integration. The magnetometer experiments currently being built will be flown on a number of meteorological satellites (DMSP series, POGS), Space Shuttle (Tether) missions, the upcoming Mars Observer Mission (MOM) and the ISTP program. Each magnetometer experiment had unique hardware and software requirements which necessitated writing custom programs and incorporating appropriate changes in the GSE hardware. In the case of the MOM and the ISTP programs, a number of components were tested for radiation hardness (primarily memory, logic and A/D chips). In the course of this, it was necessary to design and use hardware to test the devices which interfaces directly to portable PC's.

A second part of the program involved the design and calibration of various novel electrostatic analyzers. These have been designed for eventual use in various upcoming missions, including WIND and POLAR, to detect both electrons and ions. The calibration of these spectrometers has involved the design and construction of various pieces of apparatus, in addition to writing extensive software for the calibration runs. These runs are preformed in the laboratory using a positioning table and ion or electron source, both under computer control. This represents a part of an ongoing development for automating test and calibration facilities in the plasma physics laboratory.

Some additional time has been spent in analyzing data obtained from two electron spectrometers, flown on sounding rockets from Wallops Island, Virginia, during 1987 as part of the WIPP (Wave Induced Particle Precipitation) program. These spectrometers were designed to detect electrons precipitated by lightning during thunderstorms occurring in the area.

2. COOL STARS

This involves work done by Gunter Weidmann in collaboration with several staff members of the Goddard Space Flight Center. A 20-element detector array was implemented in the Postdisperser Spectrometer (PD) (partial development funded under this grant in previous years). The instrument was reconfigured as a spectrometer and now provides extended spectral coverage through the array. This makes possible the acquisition of several high resolution spectrograms simultaneously. A new focal plane with a 50-element BIB array was constructed. This allows the PD to be used as an independent IR grating spectrometer without an FTS. Detailed description of the instrument are to be published in Applied Optics (Jan. 1989).

A series of observations were made with the PD and other instruments. These include:

Feb. 1988: FTS at Canada-France-Hawaii-telescope : $4.7\mu\text{m}$ CO time series observations on Arcturus(K2,III) for stellar oscillation studies. - G. Weidemann, T. Ayres (Univ. Colorado)

April 1988: Continuation of obscured stars survey at 4m-FTS, KPNO. The goal was an investigation of circumstellar envelopes using high resolution molecular line observations - G. Weidemann, D. Jennings, R.J. Boyle and D. Deming (GSFC)

May 1988: Additional $4.7\mu\text{m}$ CO observations of late type stars at 4-m FTS, KPNO. - G. Weidemann

Oct. 1988: Observations on SN1987A with PD grating spectrometer at CTIO with the aim of detecting Fe-, H- and radioactive lines at 12 and $17\mu\text{m}$ - G. Weidemann, R. Boyle and D. Jennings (GSFC)

CO spectra of cool stars acquired over the last years were analyzed. The feasibility of abundance studies with double-isotope $\Delta v=1$ line studies could be demonstrated. High precision measurements of CO line core positions were used to study the vertical velocity distribution in Arcturus' atmosphere.

Stellar temperature profiles were constructed by matching observed and theoretical spectra. The CO based models were compared to theoretical RE models and to semi-empirical models derived from the observations of high temperature ("chromospheric") diagnostics. The disagreement between the CO-based and the RE models was found to be anti-correlated with levels of chromospheric activity reported for all the stars. Stellar bifurcation models were developed based on these results.

Theoretical work in these areas included the development of a non-LTE radiation transfer code to synthesize CO $\Delta v=1$ spectra in cool stellar atmospheres. (G. Weidemann and T. Ayres). A sensitivity study was conducted aimed at establishing CO fundamental bands as empirical diagnostics for stellar photospheres/chromospheres.

3. SOLAR ASTRONOMY

Much of this work has been done by Tilak Hewagama as part of his Ph.D. dissertation. He has worked with D. Deming and D. Jennings of the Goddard Space Flight Center and D. Zipoy of the University of Maryland.

Specific projects included

1. Further development of the Stokes polarimeter which was tested in May 1988 at the McMath solar Fourier transform spectrometer. The Fresnel rhomb in the polarimeter was replaced with a quarter-wave plate and an Electro-Optic Modulator (EOM). The quarter wave plate and the EOM were configured to enable the simultaneous measurement of Stokes profiles for the 12.32 MgI emission in sunspots.
2. The Polarimeter and the Goddard cryogenic grating postdisperser were integrated with the McMath Fourier transform spectrometer for a sunspot observing program to supplement already existing observations.
3. Modeling was begun for the MgI emission in sunspots to recover vector magnetic fields from the observations.

Additional work in the area of solar astronomy was done by D.M. Zipoy of the University of Maryland who continued the development of the four element heterodyne spectrometer. This will be applies to measurements on the Sun at the National Solar Observatory at Kitt Peak.

TECHNICAL REPORT
NASA GRANT NAG5113482
CO-OPERATIVE RESEARCH IN THE SPACE SCIENCES
PERIOD MAY 1990 - MAY 1991

SOLAR ASTRONOMY

Tilak Hewagama completed work on his Ph.D. theses "Solar Polarimetry and Magnetic Fields in Sunspots". Most of the time was spent in the analysis of previously obtained polarimetric data and in preparing to report the research in scientific journals. Some time was allocated to developing a cross-dispersion spectrometer for high spectral and time resolution of the solar limb. In order to understand the Mg I emission process, it is important to find the line formation altitude in the solar atmosphere. An experiment is being designed to monitor the solar limb while the moon moves across the face of the sun. Since the lunar position with time is known accurately, it is possible to determine accurately the line formation height, if the time interval between the disappearance of the continuum and the line are measured.

Hewagama was also involved in further instrument development and observations. In preparation for the solar eclipse run of July 1991, a 10 X 50 Si:As BIB detector array was installed in the cryogenic grating postdisperser. This system was tested and evaluated in the lab for high time resolution detection. In May, the array was field tested at the McMath Solar telescope by configuring a large ambient temperature echelle in the cross-dispersion direction, and the spectral and time resolution response was evaluated.

A series of publications have resulted from this work. They include:

"Anomalous Gain in an Isotopically Mixed CO₂ Laser and Application to Absolute Wavelength Calibration" T. Hewagama, U.P. Oppenheim, M.J. Mumma, IEEE Journal of Quantum Electronics, March 1991

"Solar Magnetic Field Studies Using the 12 μ m Emission Lines. II Stokes Profiles and Vector Field Samples in Sunspots" T. Hewagama, D. Deming, D.E. Jennings, V. Osherovich, G. Wiedemann, Astrophys. J. (to be submitted)

"Observations of the 12.3 micron Mg I Emission Line During a Major Solar Flare" T. Hewagama, D.E. Jennings, V. Osherovich, G. Wiedemann, H. Zirin, 1990, Astrophys.J. Lett, 364, L49

"Solar 12 μ m Mg I Line Observations with a Large Grating

Spectrometer" G. Wiedemann, D. Deming, T. Hewagama, D.E. Jennings, G. McCabe, J. of Applied Optics (submitted)

Denise Lengyel-Frey worked on solar radio studies. An investigation into the location of type II radio emission relative to interplanetary shocks has been completed. This study has involved a detailed analysis of hundreds of spectra from 20 interplanetary type II bursts. The frequency at peak emission was determined and these frequencies have been compared with ambient solar wind plasma frequencies upstream of the shocks to determine source locations relative to the shock. The emission was found to be produced in regions which are denser than the ambient solar wind. The average ratio of source region densities to solar wind densities is consistent with the average in situ density compression ratio for type II producing shocks. This suggests that the emission is produced downstream from the shocks. This study has also yielded the first density model (dependence of density on heliocentric distance - R) for interplanetary type II source regions. It was found that the type II density model is given by

$$n(R) = 15 \pm 1/R^{1.98 \pm .1}$$

A comparison with the with the large scale solar wind density model

$$n(R) = 6.14/R^{2.10}$$

implies that source region densities evolve with heliocentric distance in a manner similar to that of the large scale solar wind. It was determined that in situ solar wind densities upstream of interplanetary shocks tend to be smaller when the shocks are nearer to the observer. There is, therefore, a tendency for shocks to disperse the solar wind densities ahead of them.

A paper entitled "Location of the Radio Emitting Regions of Interplanetary Shocks" has been submitted to the Journal of Geophysical Research. The preliminary review was favorable, and a final draft of the revised is ready to be submitted.

A major effort has involved generating image processing software to display data from the Unified Radio and Plasma Wave (URAP) experiment on board the recently launched Ulysses spacecraft. A program (SUMMARY_PLOT) has been written to plot dynamic spectra for the Radio Astronomy Receiver, Plasma Frequency Receiver, Wave Form Analyzer, and Fast Fourier Envelope Sampler instruments, which are part of the URAP experiment. Techniques have been developed to display the data from these instruments as grey-shaded images using pixels which are defined in an output font and printed as a text file. The method is extremely efficient, requiring significantly less disk space and computer time than conventional halftoning methods. The Summary Plots have been of great importance in monitoring instrument statuses and health, as well as in identifying plasma wave events in many different

frequency regimes.

SPACE SCIENCES

Dr. Dennis Chornay has been involved with several projects in the area of space science in the support of current or planned spacecraft. The work can be summarized as follows:

1) He has been involved extensively in the development of the Ground Support software for the Mars Observer Magnetometer/Electron Reflectometer experiment. This software has been used for flight software development support and during the environmental testing of the hardware.

2) He worked on a magnetic test station which has been completed and installed at GE/ASD, Princeton, NJ. The main component of the station is a computer controllable set of Helmholtz coils and two magnetic field sensors. This apparatus is currently being used to determine the magnetic dipole moments and other magnetic characteristics of various spacecraft subsystems for both the MO and WIND spacecraft. Chornay's work has involved writing control software and data fitting routines.

3) For the MO and ISTP programs, he has been involved with the testing of various components for radiation hardness (primarily memory, logic and A/D chips). Some addition to previously designed hardware and software was required to perform these tests.

4) Over the past 2 - 3 years, he has developed a computer program which will predict the total radiation dose that a satellite will encounter, as a function of different orbital parameters. This is used by the observer to select the appropriate radiation hardened devices and/or to determine the amount of shielding required. The program runs on VAX, and IBM PC, and has recently been ported over to the SUN workstation environment. Chornay has determined the radiation environment for a number of different orbits and projects.

5) Chornay has also been extensively involved in the design and testing of two different types of electrostatic analyzers (torrodial and cylindrical), used for detecting both ions and electrons in the solar wind. These will be used on the POLAR and WIND spacecraft of the ISTP program. The testing of these spectrometers has involved updating previously written software to acquire data from the instruments, as a function of the orientation of the experiment in an ion or an electron beam.

Page Intentionally Left Blank

III. Summary of Research

Solar Astronomy

Denise Lengyel-Frey continued a study of plasma waves at interplanetary shocks using observations from the instruments of the Ulysses URAP experiment. The magnetic wave activity detected in shock waves have been interpreted as whistler waves due to the reasonable agreement of observed magnetic to electric wave amplitude ratios with the parallel whistler index of refraction. However, certain discrepancies are evident, for example, the lack of correlation of magnetic wave intensities with computed electron resonant energies. Moreover, the absence of magnetic waves downstream of most shocks remains a puzzle. These problems are under investigation.

An analysis of correlations of wave activity with solar wind and shock parameters has also continued. A statistical correlation has been found between ion acoustic waves and shock Mach number. Specifically, the ratio of downstream to upstream electric field strengths of ion acoustic waves increases with increasing Mach number. A somewhat weaker correlation occurs between this ratio and the angle of the shock normal to the large scale magnetic field. Contrary to results of bow shock studies, we find no correlation of magnetic field turbulence with shock normal angle.

G. Thejappa performed the first observational tests of existing theories for the generation of type III radio bursts emitting at the fundamental plasma frequency, ω_{pe} . This study was based on local radio emission and in situ wave phenomena associated with four interplanetary type III radio bursts observed by the Unified Radio and Plasma Wave experiment on the Ulysses spacecraft. Intense Langmuir wave peaks with energy densities and rapid time variations indicative of Langmuir solitons were observed for each of these events. For each event, brightness temperatures derived from radio observations were compared with those predicted by various conversion mechanisms. The theories tested here were: (1) scattering of Langmuir waves

by thermal ions; (2) wave-wave interactions, i.e., merging and decay processes involving Langmuir and low frequency waves; (3) strong turbulence phenomena involving Langmuir solitons; and (4) direct coupling between Langmuir and electromagnetic waves due to density gradients. The mechanism of scattering on thermal ions may be ruled out as a major source of electromagnetic radiation since it yields brightness temperatures well below observed values, whereas all other mechanisms yield brightness temperatures in excess of observed values. The direct coupling mechanism appears to provide a somewhat better agreement between the predicted and observed brightness temperatures than the other mechanisms.

Space Sciences

Dennis Chornay has been involved with the test, calibration and integration of various types of electrostatic analyzers. These are the Vector Electron Ion Spectrometer (VEIS), the Strahl detector (electrons), and the DDEIS (Electrons + Ions) instruments. They are a part of the Solar Wind Experiment, which will fly on the WIND spacecraft, and the Fast Plasma Experiment, due to fly on the POLAR spacecraft. Both are a part of the ISTP program. Testing and calibration were done, including determining the response function of the instruments, for various beam energies, type and direction. He also developed computer models of the instruments in order to perform simulation runs etc. He aided in the test/calibration of the Faraday Cup instrument for the WIND spacecraft and supported various engineering tests (thermal, vibration, acoustic) on these instruments.

Chornay also investigated the radiation environment for a number of different orbits and projects (SAC, GTC, ASTRO-D, SIRE), to predict the total radiation dose that a satellite will encounter, as a function of different orbital parameters. This is used to select appropriate radiation hardened devices, and/or to determine the amount of shielding required.

He has re-written ground support software to collect and

display data, for the DMSP series of magnetometers built here and has written programs to display Voyager magnetic field data in 'near real time'. He is currently using this to investigate sources of noise in this data.

Cometary Astronomy

Xingfa Xie who is a graduate student at the University of Pennsylvania will continue in residence at the University of Maryland while engaged in a research project with M. F. A'Hearn (UMD) and M. Mumma (GSFC). He will conduct research on cometary coma, with emphasis on developing models for axisymmetric outflow, and interpretation of ro-vibrational spectra of parent volatiles.

Planetary Work

Kelly Fast will continue work on recent infrared slit spectrograph data of Jupiter. She has developed programs for turning the data into infrared images and is now looking for wavestructure at different latitudes. She has previously developed a number of programs that look for waves as a function of longitude on the planet.

IV. FUTURE RESEARCH

Solar Astronomy

D. Lengyel-Frey will undertake a detailed study of whistler wave phenomena at shocks. This will include an analysis of the whistler propagation angle needed to account for the observed electrostatic whistler component. In addition whistler properties as observed by Ulysses at shocks beyond 1 AU will be compared with previous observations of shocks at 1 AU. We also will extend our study of correlations of wave and shock properties to include a larger data sample. Another important goal will be to establish a thorough understanding of wave characteristics for in-ecliptic shocks in order to compare with observations of high latitude shocks that Ulysses is expected to encounter.

T. Golla and collaborators have identified in URAP data several bursts of high frequency Langmuir waves in close

association with the low frequency whistler waves in the interplanetary medium. They propose to study the relationship between the whistler waves and Langmuir waves. The following questions will be addressed: 1) are the Langmuir waves and whistlers nonlinearly coupled? i.e., are the whistlers the by-products of non-linear mechanisms involving Langmuir waves? 2) do they share a common highly variable source of free energy for linear instability?

They propose to study the feasibility of non-linear coupling of these waves by carefully examining the temporal correlation of the amplitudes, resonance conditions, energy conservation relationships and threshold amplitudes for all the possible non-linear interactions. It is also proposed to study the linear as well as non-linear beam-plasma instabilities both in electrostatic and electromagnetic regimes to investigate the simultaneous excitation of Langmuir and whistler waves by the electron beams. They propose to calculate the amplitude of both Langmuir and whistler waves excited by a typical electron beam and compare with observations.

The strong Langmuir turbulence has an important bearing in understanding of many problems in both theoretical and experimental plasma physics, space physics and solar radio physics. The URAP experiment on Ulysses spacecraft is well suited for study of such phenomena with its instruments like the Fast Envelope Sampler and Wave Form Analyzer. The Fast Envelope Sampler with its high time resolution ≈ 1 ms indicates the smallest possible spatial scales of Langmuir turbulence as predicted by strong turbulence theories whereas Wave Form Analyzer can detect the low frequency waves which may be the by-products of the possible Langmuir wave collapse. They intend to study strong Langmuir turbulence in the solar wind and interplanetary conditions theoretically and compare with Ulysses observations.

The high frequency ion-acoustic wave phenomena is very common at interplanetary shocks. The excitation of such waves in

the shocks and their possible implication for the wave phenomena in the collisionless shocks are still unexplored areas. We propose to study these waves observationally at collisionless interplanetary shocks observed by the Ulysses spacecraft to understand the possible physical conditions for excitation and growth of such high frequency ion-acoustic waves. We also propose to study these waves theoretically to understand the probable physical conditions for their excitation.

Space Sciences

Over the following year, Chornay will support the integration of the Wind and Polar experiments at GE-ASTRO (NJ), the builders of the spacecraft, in addition to performing final calibrations here, prior to launch.

He also will be devising algorithms, (data collection modes) for the Strahl detector, for use during flight, and working with other members of the team to incorporate this new data into existing data analysis routines and is planning to be involved with various aspects of data reduction and interpretation for these experiments.

He will continue to work with the Voyager magnetic field data, investigate radiation environments for potential new projects, and write ground support software for new magnetometer experiments being developed in the laboratory.

Space Sciences

Dennis Chornay has continued with the test, calibration and integration of a number of different types of electrostatic analyzers. These are the Vector Electron Ion Spectrometer (VEIS), the Strahl detector (electrons), and a Faraday Cup detector. Together they form the Solar Wind Experiment, which will fly on the WIND spacecraft early next year. He has also been involved with DDEIS (Electrons + Ions) instrument, and the Parallel Plate Analyzer (Electrons). They form the Fast Plasma Experiment, due to fly on the POLAR spacecraft. Both spacecraft are a part of the ISTP program. Dennis Chornay supported various engineering tests (thermal, vibration, acoustic etc.) of these instruments, both here and at Martin Marietta (the spacecraft builders) located in East Windsor, N.J. He was involved in developing computer models of the instruments in order to perform simulation run. He investigated the radiation environment for a number of different orbits and projects (including SAC, GTC, ASTRO-D, SIRE), to predict the total radiation dose that a satellite will encounter, as a function of different orbital parameters. Dennis Chornay rewrote ground support software to collect and display data, for the DMSP series of magnetometers built here.

Cometary Astronomy

Xingfa Xie who is a graduate student at the University of Pennsylvania will continue in residence at the University of Maryland while engaged in a research project with M. F. A'Hearn (UMD) and M. Mumma (GSFC). He will conduct research on cometary coma, with emphasis on developing models for axisymmetric outflow, and interpretation of ro-vibrational spectra of parent volatiles.

Planetary Work

Kelly Fast has been working with both Drake Deming and Ted Kostiuk of NASA/GSFC Code 693. The two instruments that she has been working with are the NASA Infrared Post-Disperser (imaging) and the NASA Infrared Heterodyne Spectrometer, both used at the NASA Infrared Telescope Facility on Mauna Kea in Hawaii.

The software that was originally written in FORTRAN for working with the

post-disperser Jupiter images of 4/92 was rewritten in IDL to make use of the display and array handling capabilities of that language. It is also anticipated that some of this software will be useful for data from an upcoming observing run at the European Southern Observatory using a different thermal infrared imaging instrument, TIMMI.

All analysis of the 4/92 Jupiter images continued, with the focus on the construction of line images with the continuum contribution removed (ethane, ammonia, acetylene). These were producing anomalous results, indicating a possible sensitivity gradient across the detector. She later determined that the problem was one of saturation at one end of the detector, but that does not seem to totally account for what is seen, but it appears that the images will not be useful for the molecule studies. The images, when not continuum subtracted, do appear to be useful for studying temperatures.

Another set of post-disperser images of Jupiter was taken in 5/93. These had much better signal-to-noise, and the focus was the equatorial region of Jupiter in order to search for tide signatures. Using her previously written software, and after writing additional code, she reduced and corrected the data and put them in a form for Drake Deming to use with his tide study.

Over the summer, Kelley Fast started working with the data from the Infrared Heterodyne Spectrometer. The ethane and ethylene data from 2/93 were reduced and the ethylene spectra were modelled using the program that exists for that purpose. The models were used in Ted Kostiuik's and Tim Livengood's talks at the AAS Division of Planetary Science meeting in October. Kelley Fast was a co-author on both talks.

Ethane measurements of Titan were made with the heterodyne spectrometer in August of this year, and modelling the spectra is underway. They have proven to be difficult to model, which could have to do with as yet unidentified lines in the spectra that the modelling program therefore cannot take into account. This has also been a problem with the modelling of the ethylene and ethane spectra of 2/93. It is hoped that laboratory measurements or overhauling the modelling program will improve the modelling process. Even so, it is hoped that more accurate modelling of

the Titan spectra taken of eastern and western limbs of the satellite will tell something about the wind speeds.

IV. FUTURE RESEARCH

Solar Astronomy

Thejappa Golla and collaborators have identified in URAP data several bursts of high frequency Langmuir waves in close association with the low frequency whistler waves in the interplanetary medium. They propose to study the relationship between the whistler waves and Langmuir waves. The following questions will be addressed: 1) are the Langmuir waves and whistlers nonlinearly coupled? i.e., are the whistlers the by-products of non-linear mechanisms involving Langmuir waves? 2) do they share a common highly variable source of free energy for linear instability?

They propose to study the feasibility of non-linear coupling of these waves by carefully examining the temporal correlation of the amplitudes, resonance conditions, energy conservation relationships and threshold amplitudes for all the possible non-linear interactions. It is also proposed to study the linear as well as non-linear beam-plasma instabilities both in electrostatic and electromagnetic regimes to investigate the simultaneous excitation of Langmuir and whistler waves by the electron beams. They propose to calculate the amplitude of both Langmuir and whistler waves excited by a typical electron beam and compare with observations.

The strong Langmuir turbulence has an important bearing in understanding of many problems in both theoretical and experimental plasma physics, space physics and solar radio physics. The URAP experiment on Ulysses spacecraft is well suited for study of such phenomena with its instruments like the Fast Envelope Sampler and Wave Form Analyzer. The Fast Envelope Sampler with its high time resolution 1ms indicates the smallest possible spatial scales of Langmuir turbulence as predicted by strong turbulence theories whereas Wave Form Analyzer can detect the low frequency waves which may be the by-products of the possible Langmuir wave collapse. They intend to study strong Langmuir turbulence in the solar wind and

interplanetary conditions theoretically and compare with Ulysses observations.

The high frequency ion-acoustic wave phenomena is very common at interplanetary shocks. The excitation of such waves in the shocks and their possible implication for the wave phenomena in the collisionless shocks are still unexplored areas. We propose to study these waves observationally at collisionless interplanetary shocks observed by the Ulysses spacecraft to understand the possible physical conditions for excitation and growth of such high frequency ion-acoustic waves. We also propose to study these waves theoretically to understand the probable physical conditions for their excitation.

Denise Lengyel-Frey will undertake a detailed study of whistler wave phenomena at shocks. This will include an analysis of the whistler propagation angle needed to account for the observed electrostatic whistler component. In addition whistler properties as observed by Ulysses at shocks beyond 1 AU will be compared with previous observations of shocks at 1 AU. We also will extend our study of correlations of wave and shock properties to include a larger data sample. Another important goal will be to establish a thorough understanding of wave characteristics for in-ecliptic shocks in order to compare with observations of high latitude shocks that Ulysses is expected to encounter.

Bob MacDowall will be involved in the support of the Ulysses Unified Radio and Plasma Wave Experiment (URAP) and other spacecraft wave observations, the University of Maryland is requested to carry out analyses in 1994 in as many of the following areas as feasible: (1) study of morphological characteristics of type II and type III radio bursts observed from high heliographic latitudes and comparison of these results to in-ecliptic observations; (2) study of in situ waves associated with type III radio bursts, with the goal of constraining the emission mechanisms and beam stabilization processes; (3) study of ion-acoustic-like waves in the solar wind, with the goal of explaining the mechanism(s) responsible for their generation; (4) studies of other low frequency waves observed by URAP and other experiments in the vicinity of shocks, magnetic clouds, and elsewhere in the interplanetary medium, including their correlation with particle experiments; (5) statistical studies of high-

latitude plasma waves and comparison to in-ecliptic observations, accompanied by theoretical/modelling analysis to explain the observed differences; (6) implementation of other studies taking advantage of the unique high-latitude observations of the Ulysses spacecraft; (7) implementation and enhancement of image analysis and display software to be used for the above and other related projects.

Space Sciences

Dennis Chornay will be involved - the following projects: Continue to support the integration of the Wind and Polar experiments at Martin Marietta, N.J., in addition to performing final calibrations and refurbishment, prior to launch. Help devise algorithms, (data collection modes) for the Strahl detector, for use during flight, and working with other members of the team to incorporate this new data into existing data analysis routines. Involved with various aspects of data reduction and interpretation for these experiments. Make hardware and software enhancements in the Ion/Electron Beam calibration facility here. Work with Voyager magnetic field data. Investigate radiation environments for possible new projects. Write ground support software, and possibly design some hardware for the new magnetometer experiments being developed in the laboratory, in particular for the Cluster and SAC-B projects.

Planetary

Kelly Fast will continue her studies of the Titan heterodyne data. She also anticipates working on an analysis of Jupiter images from the anticipated March 1994 ESO/TIMMI observing run and IR studies of the impact of Comet Shoemaker-Levy on Jupiter this summer.

III SUMMARY OF PROGRESS IN PAST 12 MONTHS

1. GEOPHYSICAL STUDIES

Several projects have been undertaken involving the development and calibration of advanced instrumentation for geophysical studies in the areas of the Earth's magnetic field, terrestrial lightning and plasma research. Most of the work has been done by Dr. Dennis Chornay in conjunction with the scientific staff in the Laboratory for Extraterrestrial Physics at the Goddard Space Flight Center.

The first project involved calibrating and verifying the correct operation of sensitive fluxgate magnetometers. This work was done using previously developed Ground Support Equipment (GSE) which operates in conjunction with a PC. The test of the magnetometers covered conditions in the laboratory, during environmental testing, and during spacecraft integration. The magnetometer experiments currently being built will be flown on a number of meteorological satellites (DMSP series, POGS), Space Shuttle (Tether) missions, the upcoming Mars Observer Mission (MOM) and the ISTP program. Each magnetometer experiment had unique hardware and software requirements which necessitated writing custom programs and incorporating appropriate changes in the GSE hardware. In the case of the MOM and the ISTP programs, a number of components were tested for radiation hardness (primarily memory, logic and A/D chips). In the course of this, it was necessary to design and use hardware to test the devices which interfaces directly to portable PC's.

A second part of the program involved the design and calibration of various novel electrostatic analyzers. These have been designed for eventual use in various upcoming missions, including WIND and POLAR, to detect both electrons and ions. The calibration of these spectrometers has involved the design and construction of various pieces of apparatus, in addition to writing extensive software for the calibration runs. These runs are preformed in the laboratory using a positioning table and ion or electron source, both under computer control. This represents a part of an ongoing development for automating test and calibration facilities in the plasma physics laboratory.

Some additional time has been spent in analyzing data obtained from two electron spectrometers, flown on sounding rockets from Wallops Island, Virginia, during 1987 as part of the WIPP (Wave Induced Particle Precipitation) program. These spectrometers were designed to detect electrons precipitated by lightning during thunderstorms occurring in the area.

2. COOL STARS

This involves work done by Gunter Weidmann in collaboration with several staff members of the Goddard Space Flight Center. A 20-element detector array was implemented in the Postdisperser Spectrometer (PD) (partial development funded under this grant in previous years). The instrument was reconfigured as a spectrometer and now provides extended spectral coverage through the array. This makes possible the acquisition of several high resolution spectrograms simultaneously. A new focal plane with a 50-element BIB array was constructed. This allows the PD to be used as an independent IR grating spectrometer without an FTS. Detailed description of the instrument are to be published in Applied Optics (Jan. 1989).

A series of observations were made with the PD and other instruments. These include:

Feb. 1988: FTS at Canada-France-Hawaii-telescope : $4.7\mu\text{m}$ CO time series observations on Arcturus(K2,III) for stellar oscillation studies. - G. Weidemann, T. Ayres (Univ. Colorado)

April 1988: Continuation of obscured stars survey at 4m-FTS, KPNO. The goal was an investigation of circumstellar envelopes using high resolution molecular line observations - G. Weidemann, D. Jennings, R.J. Boyle and D. Deming (GSFC)

May 1988: Additional $4.7\mu\text{m}$ CO observations of late type stars at 4-m FTS, KPNO. - G. Weidemann

Oct. 1988: Observations on SN1987A with PD grating spectrometer at CTIO with the aim of detecting Fe-, H- and radioactive lines at 12 and $17\mu\text{m}$ - G. Weidemann, R. Boyle and D. Jennings (GSFC)

CO spectra of cool stars acquired over the last years were analyzed. The feasibility of abundance studies with double-isotope $\Delta v=1$ line studies could be demonstrated. High precision measurements of CO line core positions were used to study the vertical velocity distribution in Arcturus' atmosphere.

Stellar temperature profiles were constructed by matching observed and theoretical spectra. The CO based models were compared to theoretical RE models and to semi-empirical models derived from the observations of high temperature ("chromospheric") diagnostics. The disagreement between the CO-based and the RE models was found to be anti-correlated with levels of chromospheric activity reported for all the stars. Stellar bifurcation models were developed based on these results.

Theoretical work in these areas included the development of a non-LTE radiation transfer code to synthesize CO $\Delta v=1$ spectra in cool stellar atmospheres. (G. Weidemann and T. Ayres). A sensitivity study was conducted aimed at establishing CO fundamental bands as empirical diagnostics for stellar photospheres/chromospheres.

3. SOLAR ASTRONOMY

Much of this work has been done by Tilak Hewagama as part of his Ph.D. dissertation. He has worked with D. Deming and D. Jennings of the Goddard Space Flight Center and D. Zipoy of the University of Maryland.

Specific projects included

1. Further development of the Stokes polarimeter which was tested in May 1988 at the McMath solar Fourier transform spectrometer. The Fresnel rhomb in the polarimeter was replaced with a quarter-wave plate and an Electro-Optic Modulator (EOM). The quarter wave plate and the EOM were configured to enable the simultaneous measurement of Stokes profiles for the 12.32 MgI emission in sunspots.
2. The Polarimeter and the Goddard cryogenic grating postdisperser were integrated with the McMath Fourier transform spectrometer for a sunspot observing program to supplement already existing observations.
3. Modeling was begun for the MgI emission in sunspots to recover vector magnetic fields from the observations.

Additional work in the area of solar astronomy was done by D.M. Zipoy of the University of Maryland who continued the development of the four element heterodyne spectrometer. This will be applies to measurements on the Sun at the National Solar Observatory at Kitt Peak.

TECHNICAL REPORT
NASA GRANT NAG5113482
CO-OPERATIVE RESEARCH IN THE SPACE SCIENCES
PERIOD MAY 1990 - MAY 1991

SOLAR ASTRONOMY

Tilak Hewagama completed work on his Ph.D. theses "Solar Polarimetry and Magnetic Fields in Sunspots". Most of the time was spent in the analysis of previously obtained polarimetric data and in preparing to report the research in scientific journals. Some time was allocated to developing a cross-dispersion spectrometer for high spectral and time resolution of the solar limb. In order to understand the Mg I emission process, it is important to find the line formation altitude in the solar atmosphere. An experiment is being designed to monitor the solar limb while the moon moves across the face of the sun. Since the lunar position with time is known accurately, it is possible to determine accurately the line formation height, if the time interval between the disappearance of the continuum and the line are measured.

Hewagama was also involved in further instrument development and observations. In preparation for the solar eclipse run of July 1991, a 10 X 50 Si:As BIB detector array was installed in the cryogenic grating postdisperser. This system was tested and evaluated in the lab for high time resolution detection. In may, the array was field tested at the McMath Solar telescope by configuring a large ambient temperature echelle in the cross-dispersion direction, and the spectral and time resolution response was evaluated.

A series of publications have resulted from this work. They include:

"Anomalous Gain in an Isotopically Mixed CO₂ Laser and Application to Absolute Wavelength Calibration" T. Hewagama, U.P. Oppenheim, M.J. Mumma, IEEE Journal of Quantum Electronics, March 1991

"Solar Magnetic Field Studies Using the 12 μ m Emission Lines. II Stokes Profiles and Vector Field Samples in Sunspots" T. Hewagama, D. Deming, D.E. Jennings, V. Osherovich, G. Wiedemann, Astrophys. J. (to be submitted)

"Observations of the 12.3 micron Mg I Emission Line During a Major Solar Flare" T. Hewagama, D.E. Jennings, V. Osherovich, G. Wiedemann, H. Zirin, 1990, Astrophys.J. Lett, 364, L49

"Solar 12 μ m Mg I Line Observations with a Large Grating

Spectrometer" G. Wiedemann, D. Deming, T. Hewagama, D.E. Jennings, G. McCabe, J. of Applied Optics (submitted)

Denise Lengyel-Frey worked on solar radio studies. An investigation into the location of type II radio emission relative to interplanetary shocks has been completed. This study has involved a detailed analysis of hundreds of spectra from 20 interplanetary type II bursts. The frequency at peak emission was determined and these frequencies have been compared with ambient solar wind plasma frequencies upstream of the shocks to determine source locations relative to the shock. The emission was found to be produced in regions which are denser than the ambient solar wind. The average ratio of source region densities to solar wind densities is consistent with the average in situ density compression ratio for type II producing shocks. This suggests that the emission is produced downstream from the shocks. This study has also yielded the first density model (dependence of density on heliocentric distance - R) for interplanetary type II source regions. It was found that the type II density model is given by

$$n(R) = 15 \pm 1/R^{1.98 \pm .1}$$

A comparison with the with the large scale solar wind density model

$$n(R) = 6.14/R^{2.10}$$

implies that source region densities evolve with heliocentric distance in a manner similar to that of the large scale solar wind. It was determined that in situ solar wind densities upstream of interplanetary shocks tend to be smaller when the shocks are nearer to the observer. There is, therefore, a tendency for shocks to disperse the solar wind densities ahead of them.

A paper entitled "Location of the Radio Emitting Regions of Interplanetary Shocks" has been submitted to the Journal of Geophysical Research. The preliminary review was favorable, and a final draft of the revised is ready to be submitted.

A major effort has involved generating image processing software to display data from the Unified Radio and Plasma Wave (URAP) experiment on board the recently launched Ulysses spacecraft. A program (SUMMARY_PLOT) has been written to plot dynamic spectra for the Radio Astronomy Receiver, Plasma Frequency Receiver, Wave Form Analyzer, and Fast Fourier Envelope Sampler instruments, which are part of the URAP experiment. Techniques have been developed to display the data from these instruments as grey-shaded images using pixels which are defined in an output font and printed as a text file. The method is extremely efficient, requiring significantly less disk space and computer time than conventional halftoning methods. The Summary Plots have been of great importance in monitoring instrument statuses and health, as well as in identifying plasma wave events in many different

frequency regimes.

SPACE SCIENCES

Dr. Dennis Chornay has been involved with several projects in the area of space science in the support of current or planned spacecraft. The work can be summarized as follows:

1) He has been involved extensively in the development of the Ground Support software for the Mars Observer Magnetometer/Electron Reflectometer experiment. This software has been used for flight software development support and during the environmental testing of the hardware.

2) He worked on a magnetic test station which has been completed and installed at GE/ASD, Princeton, NJ. The main component of the station is a computer controllable set of Helmholtz coils and two magnetic field sensors. This apparatus is currently being used to determine the magnetic dipole moments and other magnetic characteristics of various spacecraft subsystems for both the MO and WIND spacecraft. Chornay's work has involved writing control software and data fitting routines.

3) For the MO and ISTP programs, he has been involved with the testing of various components for radiation hardness (primarily memory, logic and A/D chips). Some addition to previously designed hardware and software was required to perform these tests.

4) Over the past 2 - 3 years, he has developed a computer program which will predict the total radiation dose that a satellite will encounter, as a function of different orbital parameters. This is used by the observer to select the appropriate radiation hardened devices and/or to determine the amount of shielding required. The program runs on VAX, and IBM PC, and has recently been ported over to the SUN workstation environment. CHornay has determined the radiation environment for a number of different orbits and projects.

5) Chornay has also been extensively involved in the design and testing of two different types of electrostatic analyzers (torrodial and cylindrical), used for detecting both ions and electrons in the solar wind. These will be used on the POLAR and WIND spacecraft of the ISTP program. The testing of these spectrometers has involved updating previously written software to acquire data from the instruments, as a function of the orientation of the experiment in an ion or an electron beam.